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Searches for SUSY at the Tevatron

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Abstract.

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Searches for SUSY at the Tevatron

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Abstract. This paper presents recent results on Supersymmetry searches in various channels from the CDF and D0 experiments at the Tevatron.
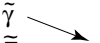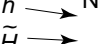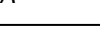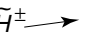
I SUPERSYMMETRY

The Standard Model (SM) very successfully describes the existing experimental information. But it has several problems from the theoretical point of view. The SM Lagrangian contains terms that are divergent unless exceptional fine tuning takes place [1]. In addition it fails to provide a dark matter candidate.

SUperSYmmetric (SUSY) model [2] introduces a new type of symmetry, between bosons and fermions. It assigns to each of the known particles a superpartner with a spin different by $\frac{1}{2}$. Table I lists ordinary particles and corresponding to them superparticles as predicted by the Minimal Supersymmetric Standard Model (MSSM) [2]. Note that the MSSM requires two Higgs doublets and that the superpartners of gauge and Higgs bosons do mix forming four neutralinos and two charginos.

SUSY solves the problem of fine-tuning and provides a dark matter candidate. The price for this is a large number of free parameters in the model. This number can be greatly reduced if we demand a grand unification [3]. In the supergravity inspired approach, called SUGRA, only 5 independent parameters survive : M_0 , $M_{1/2}$, A_t, $\tan \beta$ and $sgn(\mu)$, where M_0 is the common boson mass, $M_{1/2}$ is the common fermion mass at the GUT scale, A_t is the trilinear coupling, $\tan \beta$ is the ratio of the vacuum expectation values of the two Higgs doublets and μ is the Higgs mass parameter.

If R parity is conserved (i.e. decay products of a supersymmetric particle include at least one supersymmetric particle), then the Lightest Supersymmetric Particle (LSP) must be stable, and neutral for cosmological reasons. From the experimental point of view, a stable neutral LSP escapes the detector undetected manifesting

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[1] representing the CDF and D0 collaborations

Particle			Sparticle			
Fermion *(spin 1/2)*	Lepton	ℓ	*Sfermion* *(spin 0)*	Slepton	$\tilde{\ell}_L$, $\tilde{\ell}_R$	(only $\tilde{v}_L$)
	Quark	q		Squark	$\tilde{q}_L$, $\tilde{q}_R$	($\tilde{b}_{1,2}$, $\tilde{t}_{1,2}$)
(spin 1)	Gluon	g	*(spin 1/2)*	Gluino	$\tilde{g}$	
Gauge Boson *(spin 1)*	Photon	γ	*Gaugino* *(spin 1/2)*	Photino	$\tilde{\gamma}$	
	Z boson	Z		Zino	$\tilde{Z}$	
Higgs Boson *(spin 0)*	light Higgs	h		Higgsino	$\tilde{h}$	Neutralino $\tilde{\chi}^0_{1,2,3,4}$
	heavy Higgs	H	*Higgsino* *(spin 1/2)*	Higgsino	$\tilde{H}$	
	Pseudoscalar Higgs	A		Higgsino	$\tilde{A}$	
Gauge Boson *(spin 1)*	W boson	$W^{\pm}$	*Gaugino* *(spin 1/2)*	Wino	$\widetilde{W}^{\pm}$	Chargino
Higgs Boson *(spin 0)*	Charged Higgs	$H^{\pm}$	*Higgsino* *(spin 1/2)*	Higgsino	$\tilde{H}^{\pm}$	$\tilde{\chi}^{\pm}_{1,2}$
(spin 2)	Graviton	G	*(spin 3/2)*	Gravitino	$\widetilde{G}$	

itself as missing transverse energy ($\not{E}_T$). $\not{E}_T$ is a very important attribute of all SUSY signatures discussed in this paper.

Here we present the results on searches for SUSY particles performed recently with the CDF and D0 detectors which operate at the Tevatron $p\bar{p}$ collider at Fermilab. The center of mass energy of the $p\bar{p}$ collisions is 1.8 TeV. The paper summarizes the results of several analyses : $\not{E}_T$ and jets from D0, trilepton analysis from CDF and searches for SUSY with γ signatures from D0 and CDF.

II   SQUARK AND GLUINO SEARCHES

A classical signature for SUSY is the multiple jets and $\not{E}_T$ where jets are produced in direct and cascade decays of squarks and gluinos.

$$p\bar{p} \rightarrow (\tilde{q}\tilde{q}, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}),\ \tilde{g} \rightarrow q\bar{q}\tilde{\chi}^0_i,\ \tilde{g} \rightarrow q\bar{q}'\tilde{\chi}^{\pm}_i,\ \tilde{q} \rightarrow q\tilde{\chi}^0_i,\ \tilde{q} \rightarrow q'\tilde{\chi}^{\pm}_i.$$

The final event signature depends on the decay channels of the charginos and neutralinos and involve $\not{E}_T$ and multiple jets. Here and below the $\tilde{\chi}^0_1$ is assumed to be the LSP and R parity is assumed to be conserved. Therefore the $\tilde{\chi}^0_1$ is stable and carries away energy producing the $\not{E}_T$ signature.

The D0 experiment searched for events with multiple jets and $\not{E}_T$ using the data sample of 79 pb^{-1} [4]. Three or more jets with $E_T > 25$ GeV were required where at least one of the jets is central with $E_T > 115$ GeV. Events with a large $\not{E}_T$ were selected where the $\not{E}_T$ was uncorrelated with the direction of jets. Events with isolated leptons (e/μ) were rejected.
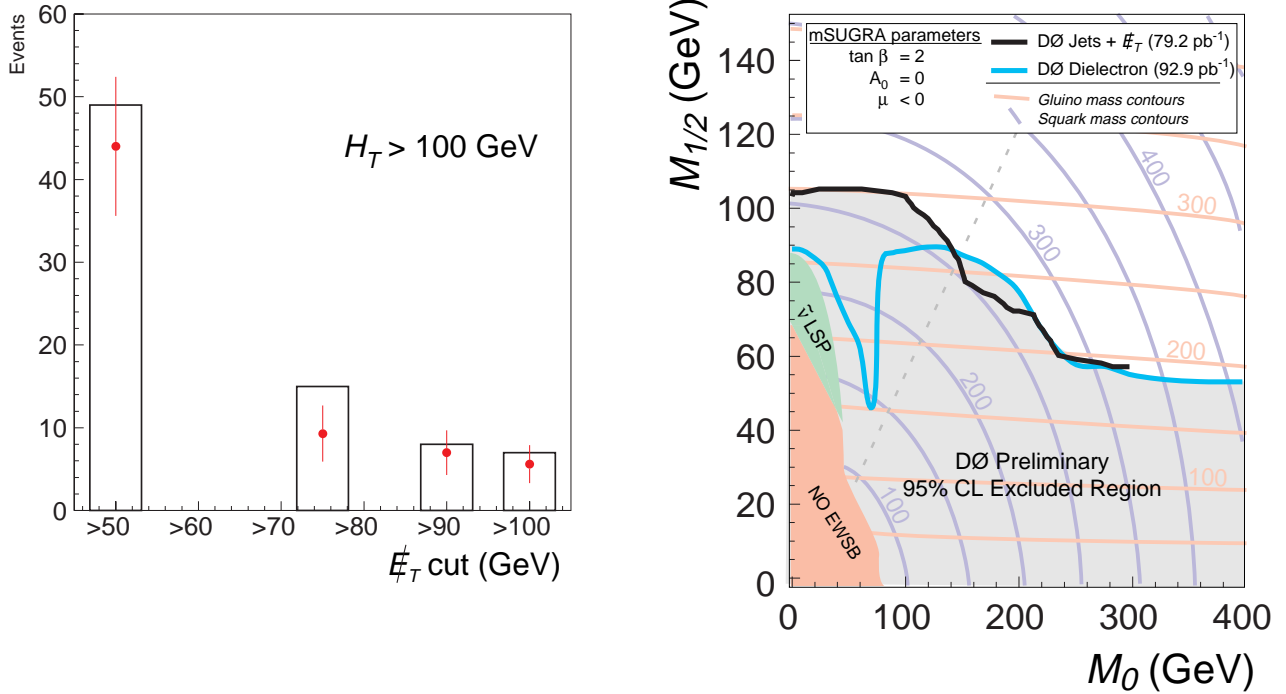
FIGURE 1. a) Comparison of the number of events observed by D0 with expected background for different values of the $\not{E}_T$ cut. b) D0 exclusion region in the $M_{1/2}$ and M_0 parameter space in minimal SUGRA.

The main backgrounds in this analysis come from W/Z + jets processes, top quark production and QCD multijet production in which the $\not{E}_T$ originates from a mismeasurement. The variable H_T (sum of E_T of the second, third, etc. jets) was found to be efficient in background suppression. Final $\not{E}_T$ and H_T cuts were optimized in each M_0 and $M_{1/2}$ point in the minimal SUGRA parameter space ($\not{E}_T \geq$ 50 - 150 GeV; $H_T \geq$ 100 - 250 GeV).

Figure 1a compares the number of observed events with expected background for different values of the $\not{E}_T$ cut. No excess of data has been found. This is interpreted as an exclusion region in the $M_{1/2}$ and M_0 parameter space (see Figure 1b).

III   SUSY IN THE TRILEPTON CHANNEL

Superpartners of gauge and Higgs bosons, charginos and neutralinos, are predicted to be the lightest supersymmetric particles in many versions of MSSM and SUGRA. If they are produced in $p\bar{p}$ collisions their decay gives a distinct trilepton + $\not{E}_T$ signature [5]:
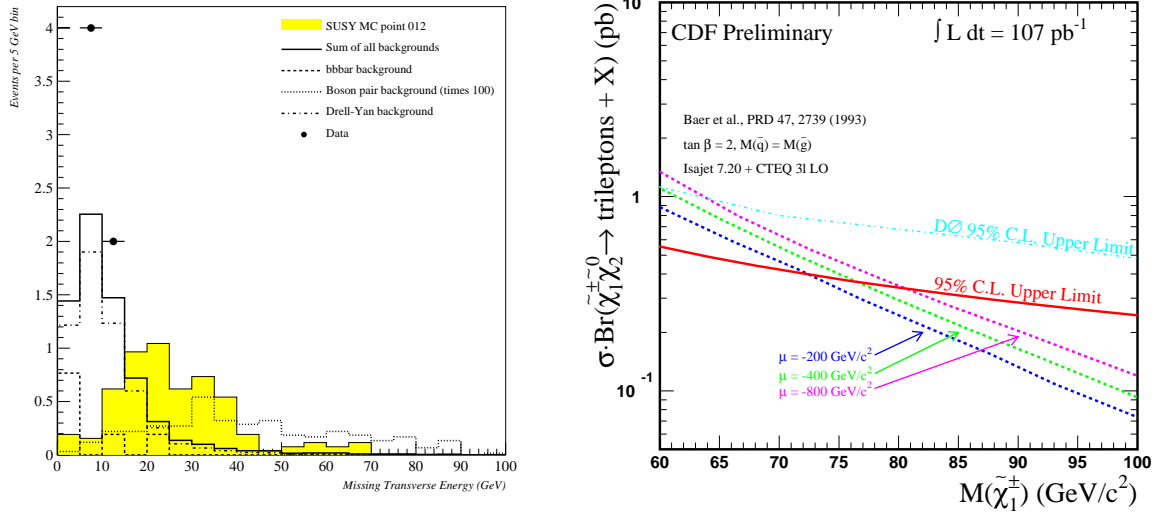
FIGURE 2. a) distribution of $\not{E}_T$ in the data, main backgrounds and one of the signal points before the final $\not{E}_T$ cut of 15 GeV at CDF. b) CDF 95% C.L. limit on the production cross section times Branching Ratio as a function of chargino mass. Overlayed are the theoretical predictions for different values of μ. Models predicting cross section that is higher than the 95% C.L. limit are excluded.

$$p\bar{p} \to \tilde{\chi}_1^+ \tilde{\chi}_2^0, \ \tilde{\chi}_1^+ \to l\nu\tilde{\chi}_1^0, \ \tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0.$$

This process is considered to be the golden signature of SUSY because of the low SM backgrounds. CDF has searched the data sample of 107 pb^{-1} for events with 3 isolated leptons and $\not{E}_T > 15 \ GeV$ and found none [6]. The expected SM background is 1.2 ± 0.2 events. This result was used to set limits on models that predict production of more than 3.2 events. Figure 2a shows the distribution of $\not{E}_T$ for the data, for main backgrounds and for one of the signal points before the final $\not{E}_T$ cut. Figure 2b shows the CDF 95% C.L. limit on the production cross section times Branching Ratio as a function of chargino mass. Overlayed are the theoretical predictions for different values of μ.

IV PHOTON ENRICHED SUSY

SUSY models predict a wide variety of signatures. After CDF recorded the famous $ee\gamma\gamma\not{E}_T$ event [7] several scenarios with photon signatures were suggested to explain it.

$E_T^\gamma > 12$ GeV Threshold		
Signature (Object)	Obs.	Expected
$\not{E}_T > 35$ GeV, $|\Delta\phi_{\not{E}_T - \text{jet}}| > 10°$	1	0.5 ± 0.1
$N_{\text{jet}} \geq 4$, $E_T^{\text{jet}} > 10$ GeV, $|\eta^{\text{jet}}| < 2.0$	2	1.6 ± 0.4
Central e or μ, $E_T^{e \text{ or } \mu} > 25$ GeV	3	0.3 ± 0.1
Central τ, $E_T^\tau > 25$ GeV	1	0.2 ± 0.1
b-tag, $E_T^b > 25$ GeV	2	1.3 ± 0.7
Central γ, $E_T^{\gamma 3} > 25$ GeV	0	0.1 ± 0.1
$E_T^\gamma > 25$ GeV Threshold		
Object	Obs.	Exp.
$\not{E}_T > 25$ GeV, $|\Delta\phi_{\not{E}_T - \text{jet}}| > 10°$	2	0.5 ± 0.1
$N_{\text{Jet}} \geq 3$, $E_T^{\text{Jet}} > 10$ GeV, $|\eta^{\text{Jet}}| < 2.0$	0	1.7 ± 1.5
Central e or μ, $E_T^{e \text{ or } \mu} > 25$ GeV	1	0.1 ± 0.1
Central τ, $E_T^\tau > 25$ GeV	0	0.03 ± 0.03
b-tag, $E_T^b > 25$ GeV	0	0.1 ± 0.1
Central γ, $E_T^{\gamma 3} > 25$ GeV	0	0.01 ± 0.01

TABLE 1. Number of observed and expected $\gamma\gamma$ events with additional objects at CDF in 85 pb^{-1}

A   Light Gravitino LSP

In the framework of gauge mediated models in the MSSM the gravitino could be the LSP [10]. For most of the parameter space within these models, the lightest neutralino decays to a photon and gravitino: $\tilde{\chi}_1^0 \to \gamma\tilde{G}$. Therefore, any pair produced sparticles will yield a pair of photons and $\not{E}_T$.

B   Search for events with $\gamma\gamma + \not{E}_T$

CDF has performed systematic searches for events with 2 photons and any additional object, $\gamma\gamma X$ [7]. The results of these searches are summarized in Table 1 for two photon energy thresholds - 12 and 25 GeV. The number of observed events is in agreement with that expected from SM sources.

In the light gravitino scenario, M_2 (SU(2) group mass parameter) is a parameter which together with $\tan\beta$ and the sign of μ controls the gaugino masses. The masses of the lightest chargino and the second lightest neutralino are approximately equal to M_2. For most of parameter space pair production of sparticles (dominated by gaugino pair production) eventually leads to final states containing $\gamma\gamma + \not{E}_T$. The results of the counting experiment in the $\gamma\gamma\not{E}_T$ channel with a $\not{E}_T$ cut at 35 GeV were used to set limits on the light gravitino models. 1 event passes all cuts with expected background of 0.5 ± 0.1 events.

Figure 3a) shows the distribution of $\not{E}_T$ before the final $\not{E}_T$ cut in the CDF $\gamma\gamma\not{E}_T$ sample. In Figure 3b) we present the excluded region of M_2 vs $\tan\beta$ plane
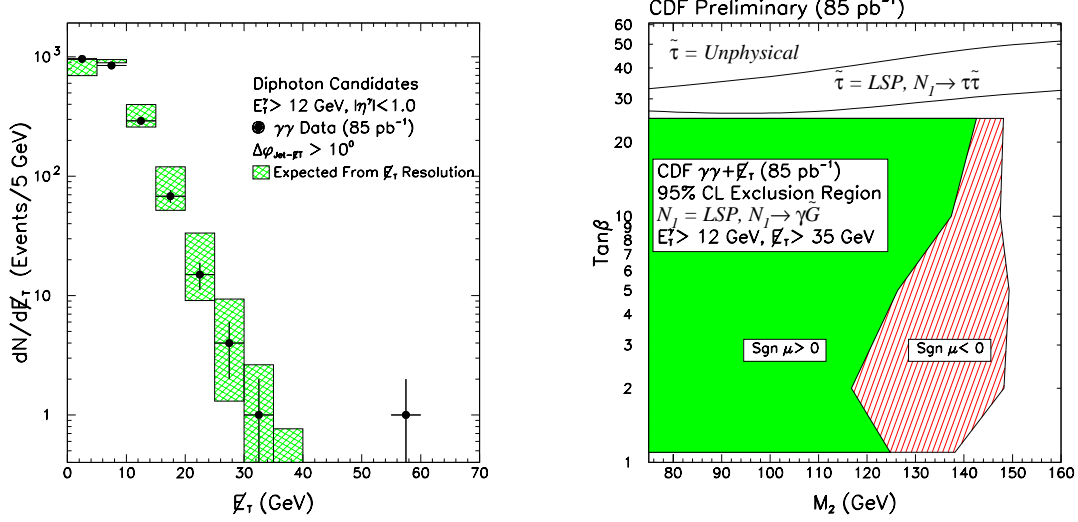
FIGURE 3. a) Distribution of $\not{E}_T$ before the final $\not{E}_T$ cut in the CDF $\gamma\gamma \not{E}_T$ sample. b) CDF excluded region of M_2 vs $\tan\beta$ plane for the positive and negative signs of μ.

for the positive and negative signs of μ.

See also [8] for $\gamma\gamma + \not{E}_T$ results from D0.

C Higgsino LSP

Another way to produce photon enriched signatures is to have a photino-like $\tilde{\chi}_2^0$ and Higgsino-like $\tilde{\chi}_1^0$. In this class of models $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + \gamma$ yielding one or more photons in the final state.

D Search for events with $\gamma + \not{E}_T$

Processes with production of Higgsino LSP

$$p\bar{p} \to (\tilde{q}, \tilde{g}, \tilde{\chi}_2^0) \to \tilde{\chi}_2^0 + X \to \gamma\tilde{\chi}_1^0 + X$$

will result in $\gamma + \not{E}_T$ events with multijets [9].

D0 analysed 99 pb^{-1} of data looking for a photon with $E_T > 20$ GeV, two or more hadronic jets with $E_T > 20$ GeV and $\not{E}_T > 25$ GeV [11]. 378 events were observed in the data. The number of data events agrees well with the expected background. The background is dominated by fakes (fake $\not{E}_T$ and a real or fake γ). The contribution from W/Z production is small.

The event selection was optimized in the $\not{E}_T$, H_T plane ($\not{E}_T > 45$ GeV, $H_T > 220$ GeV). After final cuts 5 events have been found in data with 8.1 ± 5.8 background events expected. For $m(\tilde{q}) = m(\tilde{g}) = 300$ Gev/c^2 the efficiency for the signal predicted by the Higgsino LSP model is 21.5% and 11.3 events are expected. Figure 4a
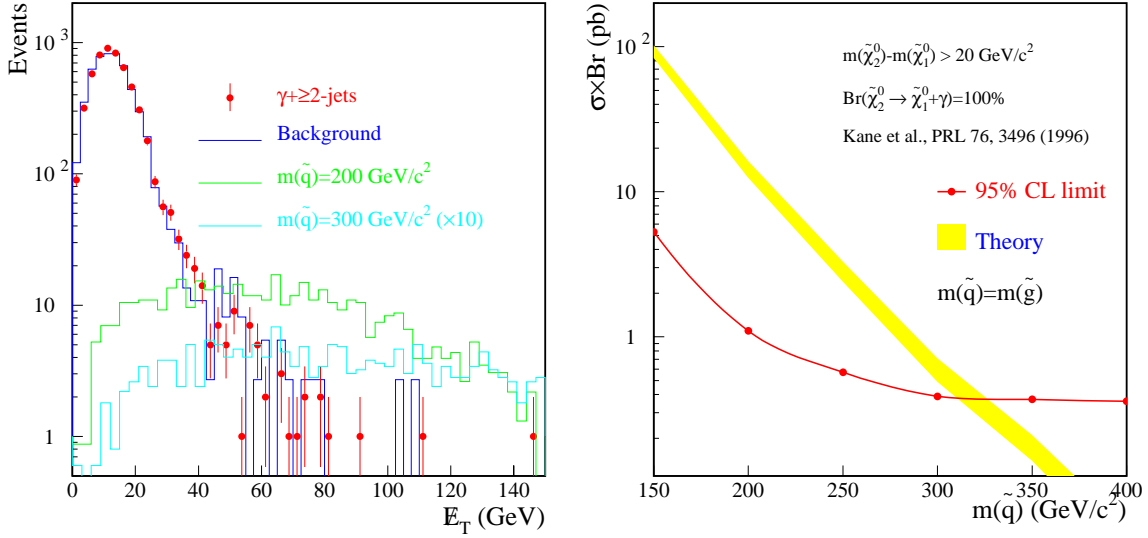
FIGURE 4. a) Distribution of $\not{E}_T$ before the final cuts. b) D0 95% CL limit on the cross section with overlayed theoretical prediction.

shows the distribution of $\not{E}_T$ before the final cuts. Figure 4b shows the 95% CL limit on the cross section with overlayed theoretical prediction.

E   Search for events with γ + b + $\not{E}_T$

In association with the light stop (top superpartner) hypothesis the Higgsino LSP scenario yields a photon plus heavy flavor plus $\not{E}_T$ signature [12]:

$$p\bar{p} \to \tilde{\chi}_2^0 \tilde{\chi}_1^+ , \ \tilde{\chi}_2^0 \to \gamma\tilde{\chi}_1^0, \ \tilde{\chi}_1^+ \to b\tilde{t}, \ \tilde{t} \to c\tilde{\chi}_1^0.$$

CDF has searched for events with an isolated photon $E_T > 25$ GeV and a b-tagged jet. The $\not{E}_T$ spectrum of these events is shown in Figure 5a. Overlayed are the background estimate and the expected signal distributions. For $\not{E}_T > 40$ GeV we find 2 events. Without performing background subtraction we set the 95% C.L. limit at 6.46 event level. We can exclude a region in squark and gluino mass plane (see Figure 5b) for the processes where squarks and gluinos cascade down to charginos and neutralinos.

V   CONCLUSION

Searches for Supersymmetric signatures at the Tevatron are consistent with SM expectations. As a result a significant area of the parameter space of various SUSY models has been excluded.

The CDF and D0 collaborations are looking forward to Run II with the Main Injector and upgraded detectors. A factor of 20 increase in luminosity will allow us
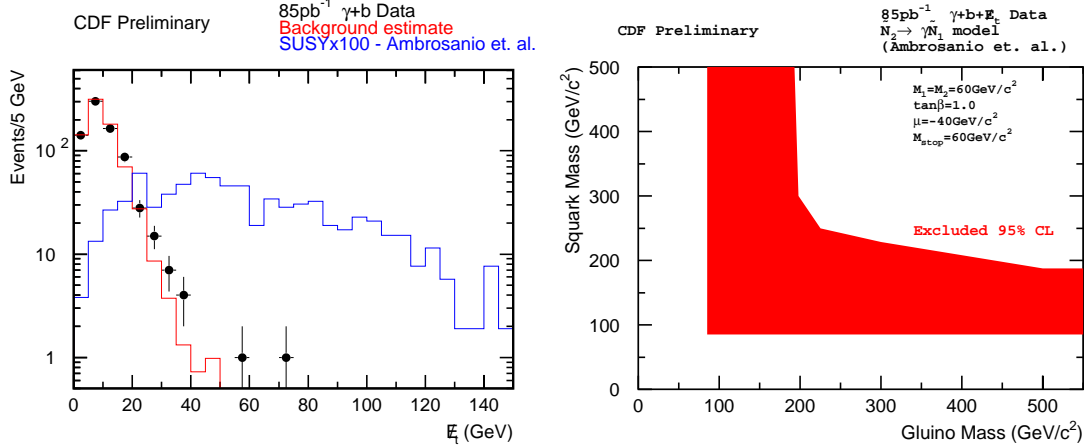
FIGURE 5. a) $\not{E}_T$ spectrum of the γ b events. Overlayed are the background estimate and the expected signal distribution. b) Excluded by CDF region in squark and gluino mass plane.

to probe deeper the Supersymmetric parameter space and either discover or rule out a wider class of models.

VI ACKNOWLEDGEMENTS

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